Connecting E-Hailing to Mass Transit Platform

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Challenges

Chronic traffic congestion (Over $100 billion/year for wasted time and fuel in the US)
Elevated environment impacts of travel (about a quarter of greenhouse gas emissions)
Challenges

Added vulnerability to energy insecurity (60% petroleum in the US)
Limited mobility options for those who cannot drive.
Towards sustainable transportation

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- Reinventing transit systems;
- Analyzing new mobility services
Disruptive technologies

- Mobile computing and communication technologies
Disruptive technologies

- New vehicle technology
Disruptive technologies

- Ridesourcing and ridesharing
Disruptive technologies

- Social network
Future of personal mobility

Most travellers will give up not only driving but likely also car ownership; personal travel will be mostly provided as a public service, operated by driverless cars; traffic congestion will be here to stay (if not becoming worse).

What do we need to get there?

- New strategies for design and operation
- New theories for regulations and policies
- New mathematical models for forecasting and planning
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Case of Transportation Network Companies

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Uber and Didi Chuxing are valued currently at $68B and $36B, respectively.
Case of Transportation Network Companies

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- There are signs that TNCs’ expansion in the market has slowed in recent months.

- TNCs’ current business model, built on e-hailing, economy of scale and aggressive pricing, can only go so far (Nie, 2016).
Case of Transportation Network Companies

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- But can driverless cars solve all the problems?
- Much greater ride consolidation/sharing must be achieved.
- Structured routes must be put in place, along with flexible routes.
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- Flexible routes directly responds to demand, similar to e-hailing.

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CREDIT is a prototype of **futuristic mass transit platforms**.
The remaining of this talk will focus on hybrid design:

- Hybrid design
- Vehicle routing - sequencing, ride sharing etc.
- Operational strategies - headway control, coordination etc.
- Trip planning - personalized service and pricing
Research agenda

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Research question: hybrid design

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- What is the optimal route structure?
- How to estimate optimal design parameters?
- How to perform a detailed design based on local characteristics?
Design concepts

- Sketchy design models under idealized conditions

Hybrid design

A continuous approximation approach

First consider a hybrid design called paired-line system. Flexible routes are operated in parallel with paired fixed-route transit lines using smaller vehicles. It only serves passengers whose access distance exceeds certain threshold, which itself is a design parameter.

Conclusions

Nie

Credit
Design concepts

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- First consider a hybrid design called paired-line system.
  - Flexible routes are operated in parallel with paired fixed-route transit lines using smaller vehicles.
  - It only serves passengers whose access distance exceeds certain threshold, which itself is a design parameter.
  - Design of flexible and structured routes is tightly integrated.
Sketchy design model

- Square service area of side length $D$ and street spacing of $s$.
Sketchy design model

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- Demand generation rate $\lambda$ as a homogeneous spatial Poisson process.
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Demand generation rate $\lambda$ as a homogeneous spatial Poisson process.

Structured routes operate in both directions, while flexible routes only operate in one direction.
Square service area of side length $D$ and street spacing of $s$.

Demand generation rate $\lambda$ as a homogeneous spatial Poisson process.

Structured routes operate in both directions, while flexible routes only operate in one direction.

Flexible routes serve passengers outside the designed walking area.
Assumptions

- Passengers always use the stops closest to their origin and destination. If the access distance is less than $\beta D/N$ (where $\beta \in (0, 1]$ is a design variable), passengers will choose walking; otherwise, passengers will request e-hailing.
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- Passengers travel between these stations with the least possible number of transfers and as directly as possible.
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- Passengers submit their request prior to the desired departure time. Their request will be processed in a first-come-first-serve basis.

- Passengers travel between these stations with the least possible number of transfers and as directly as possible.

- When transfer is needed, passengers randomly choose the initial direction of travel.
System Cost

- Agency Costs
  - Vehicle Distance
  - Fleet Size
  - Walking

- User Costs
  - Waiting
  - In-vehicle Time
  - Transfer
Formulation for the grid paired-line system

\[ \min z(N, H_1, H_2, \beta) \]

\[ = \pi Q Q + \pi M M + W + A + T + \frac{\delta}{v_w} e_T \]

s.t. \( H_1 > 0, H_2 > 0 \)

\[ N \in \{1, 2, \ldots, \left\lfloor \frac{D}{s} \right\rfloor \} \]

\[ 0 < \beta \leq 1. \]

where

\( N \) - number of lines;
\( H_1 \) - headway of structured routes;
\( H_2 \) - headway of flexible routes;
\( \beta \) - Walking threshold

are decision variables.

\( \pi Q, \pi M, \delta, v_{c1}, v_{c2} \) are given parameters.

\[ Q = Q_1 + Q_2 \frac{4ND}{H_1} + \frac{5ND}{2H_2} + \frac{2p_y \lambda D^3}{3N} \]

\[ M = \frac{Q_1}{v_{c1}} + \frac{Q_2}{v_{c2}} \]

\[ A = p_n \frac{2l}{v_w} \]

\[ W = p_y H_2 + \frac{H_1}{2} \left[ 1 + \frac{(N - 1)^2}{N^2} \right] \]

\[ T = \frac{E_1}{v_{c1}} + \frac{E_2}{v_{c2}} \]

\[ E_1 = \frac{0.34D(2N^2 - 2N + 1)}{N^2} ; E_2 = \frac{p_y l_y Q_2 H_2}{ND} \]

\( Q \) - total distance traveled
\( M \) - total fleet size
\( A \) - walking time
\( W \) - waiting time
\( E \) - In-vehicle travel distance
Formulation for the grid paired-line system

\[
\min z(N, H_1, H_2, \beta) = \pi Q Q + \pi M M + W + A + T + \frac{\delta}{v_w} e_T \tag{1}
\]
\[
\text{s.t. } H_1 > 0, H_2 > 0 \tag{2}
\]
\[
N \in \{1, 2, \ldots, \left\lfloor \frac{D}{s} \right\rfloor \} \tag{3}
\]
\[
0 < \beta \leq 1. \tag{4}
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\[
\text{where }
\[p_n = \begin{cases} 2\beta^2, & 0 < \beta \leq 0.5, \\ 1 - 2(1 - \beta)^2, & 0.5 < \beta \leq 1. \end{cases} \]
\[
p_y = 1 - p_n \]

is walking probability
\[
e_T = \frac{(N - 1)^2}{N^2} \]

is transfer probability, and
\[
I = \begin{cases} \frac{2\beta D}{3N}, & 0 < \beta \leq 0.5, \\ \frac{3-4(1-\beta)(1+2\beta)}{6-12(1-\beta)^2} \frac{D}{N}, & 0.5 < \beta \leq 1. \end{cases} \]
Alternative hybrid design

Paired-line system

Zone-based system
Alternative hybrid design

Paired-line system

Zone-based system

Which one is better?
Alternative route structure

Radial paired-line with flexible routes running on circular lines.

Area served by demand adaptive lines around the corresponding circular line

$\theta_r$

$S_c$

$R$

Fixed transit lines
Demand adaptive lines
Transit stop
Radial paired-line with flexible routes running on radial lines.
Non-hybrid systems

Fixed-route transit system (Daganzo 2010)
Non-hybrid systems

Fixed-route transit system (Daganzo 2010)

Flexible-route transit system (Nourbakhsh & Ouyang 2012)
The optimization problem is solved by Matlab’s built-in genetic algorithm.

Parameters used in the numerical experiments are listed below.

<table>
<thead>
<tr>
<th>Notation</th>
<th>Value</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>$s(km)$</td>
<td>0.15</td>
<td>the distance between two adjacent streets (street spacing)</td>
</tr>
<tr>
<td>$\mu($/h)$</td>
<td>20</td>
<td>value of time</td>
</tr>
<tr>
<td>$\tau_1(s)$</td>
<td>12</td>
<td>time lost per stop due to deceleration and acceleration</td>
</tr>
<tr>
<td>$\tau'_1(s)$</td>
<td>1</td>
<td>time added per boarding passenger for fixed-route vehicles</td>
</tr>
<tr>
<td>$\tau_2(s)$</td>
<td>13</td>
<td>additional pick-up and drop-off time required per passenger</td>
</tr>
<tr>
<td>$v(km/h)$</td>
<td>25</td>
<td>vehicles’ cruising speed</td>
</tr>
<tr>
<td>$v_w(km/h)$</td>
<td>2</td>
<td>walking speed</td>
</tr>
<tr>
<td>$\delta(km)$</td>
<td>0.03</td>
<td>transfer penalty expressed in terms of equivalent distance walked</td>
</tr>
<tr>
<td>$Q($/veh \cdot km)$</td>
<td>2</td>
<td>operation cost per vehicle distance</td>
</tr>
<tr>
<td>$M($/veh \cdot h)$</td>
<td>40</td>
<td>operation cost per vehicle hour</td>
</tr>
</tbody>
</table>
Grid paired-line system vs. non-hybrid systems

Cost versus demand levels for \( D = 20\text{km} \)
Sensitivity analysis: inconvenient walking

$v_w = 0.1 \text{ km/h}$
Sensitivity analysis: fast walking

\[ v_w = 3 \text{km/h} \]
Sensitivity analysis: high weight of waiting

1 unit of waiting time = 1.8 unit of in-vehicle time
Zone-based vs. line-based: total cost

![Graph showing cost comparison between zone-based and line-based designs]

- **D = 20km**

<table>
<thead>
<tr>
<th>Demand $\lambda$ (log-scale)</th>
<th>Cost (hour)</th>
</tr>
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<tbody>
<tr>
<td>10</td>
<td>0.8</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
</tr>
<tr>
<td>10</td>
<td>1.2</td>
</tr>
<tr>
<td>100</td>
<td>1.4</td>
</tr>
<tr>
<td>1000</td>
<td>1.6</td>
</tr>
<tr>
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</tbody>
</table>
Zone-based vs. line-based: number of lines

D = 20km

- Line-based
- Zone-based

Number of lines N vs. Demand λ (log-scale)
Zone-based vs. line-based: headway

![Graph showing headway vs. demand for different systems: D = 20km, Line-based Fixed, Line-based E-hailing, Zone-based.](image)
Grid vs. radial: total cost

![Graph showing cost (hour) vs. demand (log-scale) for D = 20km.]

- **Grid**
- **Radial–C–Model**
- **Radial–R–Model**
Grid vs. radial

Maximum walking distance

Total line length
Grid vs. radial

Headway of structured routes

Headway of flexible routes
Grid vs. radial

Agency cost

User cost
NetLogo is a multi-agent programmable modeling environment
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Transit System Simulation Interface developed using NetLogo.
Simulation vs. analysis results

Paired-line system

Zone-based system

D = 20km

Demand $\lambda$ (log-scale)

Cost (hour)
Simulation vs. analysis results

Radial paired-line system with circular flexible routes

Radial paired-line system with radial flexible routes
Summary of findings

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- The line-based design features a sparser structured routes but a higher dispatching frequency;
- Radial paired-line systems save about 10% system cost for larger networks with relatively high demand; and
- Analytical results match simulation results well in grid systems, but tend to overestimate the system cost in radial systems.
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What did we learn?

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- It personalizes transit services and is well equipped to balance cost and level of service.
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- It personalizes transit services and is well equipped to balance cost and level of service.
- Electrification and automation will make novel transit systems like CREDIT much more competitive.
- Transportation systems analysts have the unique skill set to contribute to the intelligence of such systems.
Where do we go from there?

Future research can further develop:

- Efficient real-time vehicle routing;
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- Coordination and control strategies;
- Personalized service and pricing;
- A high-fidelity, high-performance simulation platform
Thank you for listening!

Acknowledgement


